The Modernized Metric Sys

M E

1 INCH   1 FOOT   **Y A**

100 cm²

1 CUBIC DECIMETER
also called
1 liter
or
1000 cm³

1 LIQUID QUART
(approximately)
0.946 liter
or
946 cm³

THE International System of Units—viated SI—is a modernized version system. It was established by inter ment to provide a logical and interconne for all measurements in science, industry, SI is built upon a foundation of base unit nitions, which appear on this chart. All o

The Six Base Units of Measuren

Length   METER—m

The meter is defined as 1 650 763.73 wavelengths in vacuum of the orange-red line of the spectrum of krypton-86.

METER BAR
1 650 763.73 WAVELENGTHS
ONE
WAVELENGTH

An interferometer is used to measure length by means of light waves.

Kr⁸⁶ ATOM

The SI unit of area is the square meter (m·). Land is often measured by the hectare (10 000 square meters, or approximately 2.5 acres).
The SI unit of volume is the cubic meter (m³). Fluid volume is often measured by the liter (0.001 cubic meter).

1968

National Bureau of Standards Special Publication 304 A
(Supersedes Miscellaneous Publication 232)
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D C. 20402 · Price 20 cents

References:
NBS Handbook 102, ASTM Metric Practice Guide, 40 cents
NBS Misc. Publ. 247, Weights and Measures Standards of the United States, A Brief History, 35 cents
NBS Misc. Publ. 286, Units of Weight and Measure, Definitions and Tables of Equivalents, $1.50

Time   SECOND-s

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium atom. It is realized by tuning an oscillator to the resonance frequency of the cesium atoms as they pass through a system of magnets and a resonant cavity into a detector.

TRANSITION
— REGION —
DIRECTION OF   (CAVITY)   DIRECTION OF
MAGNETIC FIELD   OSCILLATING   MAGNETIC FIELD
                  FIELD
CESIUM
SOURCE

DETECTOR

DEFLECTING MAGNET   DEFLECTING MAGNET

FROM OSCILLATOR

A schematic of an atomic beam spectrometer. The trajectories are drawn for those atoms whose magnetic moments are "flipped" in the transition region.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.
Standard frequencies and correct time are broadcast from NBS stations WWV, WWVB, WWVH, and WWVL, and stations of the U.S. Navy.
Many shortwave receivers pick up WWV on frequencies of 2.5, 5, 10, 15, 20, and 25 megahertz. The standard radio broadcast band extends from 535 to 1605 kilohertz.
Dividing distance by time gives speed. The SI unit for speed is the meter per second (m/s), approximately 3 feet per second.
Rate of change in speed is called acceleration. The SI unit for acceleration is the meter per second per second (m/s·).

Mass   KILOGRAM—kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

U.S. PROTOTYPE
KILOGRAM
NO. 20

Closely allied to the concept of mass is that of force. The SI unit of force is the newton (N). A force of 1 newton, when applied for 1 second, will give to a 1 kilogram mass a speed of 1 meter per second (an acceleration of 1 meter per second per second).

1N

1kg

ACCELERATION OF 1m/s²

$$1N = \frac{1kg \cdot 1m}{1s^2}$$

One newton equals approximately two tenths of a pound of force.
The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about 9.8m/s .
The SI unit for work and energy of any kind is the joule (J).

$$1J = 1N \cdot 1m$$

The SI unit for power of any kind is the watt (W).

$$1W = \frac{1J}{1s}$$

This chart is one-third the actual size of the full-scale wall chart, NBS Special Publication 304, which is availabl

The Modernized Metric System

The International System of Units (SI) and its relationship to U.S. customary units

METER

INCH — **FOOT** — **YARD** — **2 FEET**

100 cm²

1 CUBIC DECIMETER
also called
1 liter
or
1000 cm³

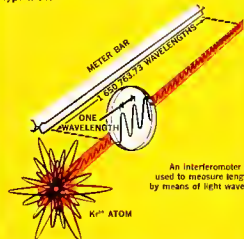**1 LIQUID QUART**
(approximately)
0.946 liter
or
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THE International System of Units—officially abbreviated SI—is a modernized version of the metric system. It was established by international agreement to provide a logical and interconnected framework for all measurements in science, industry, and commerce. SI is built upon a foundation of base units and their definitions, which appear on this chart. All other SI units are derived from these base units. Multiples and submultiples are expressed in a decimal system. Use of metric weights and measures was legalized in the United States in 1866, and our customary units of weights and measures are defined in terms of the meter and the kilogram. The only legal units for electricity and illumination in the United States are SI units.

The kilogram shown here approximates one third the size of the platinum-iridium standard of mass. One pound of the same material would be three times the size shown below.

1 pound = 0.453 592 37 kg

1 KILOGRAM **1 POUND**

The Six Base Units of Measurement
definitions, abbreviations, and some SI units derived from them

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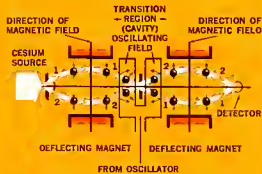The SI unit of volume is the cubic meter (m³). Fluid volume is often measured by the liter (0.001 cubic meter).

1968

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TRANSITION REGION (CAVITY) OSCILLATING FIELD
DIRECTION OF MAGNETIC FIELD — DIRECTION OF MAGNETIC FIELD
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U.S. PROTOTYPE KILOGRAM NO. 20

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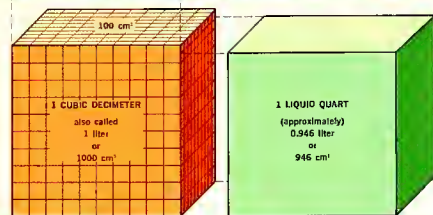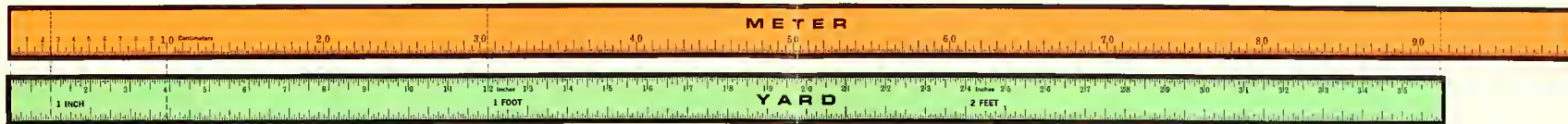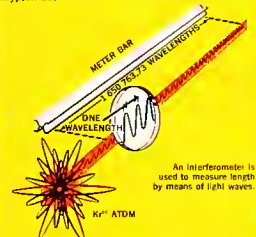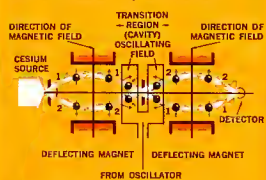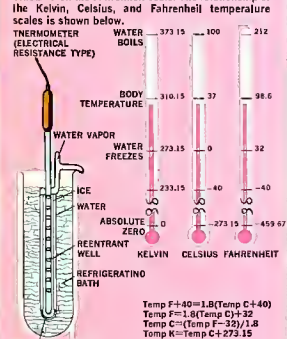The SI unit for work and energy of any kind is the joule (J).

$$1J = 1N \cdot 1m$$

The SI unit for power of any kind is the watt (W).

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Temperature — KELVIN—K

The thermodynamic or Kelvin scale of temperature used in SI has its origin or zero point at absolute zero and has a fixed point at the triple point of water defined as 273.16 kelvins. The Celsius scale is derived from the Kelvin scale. The triple point is defined as 0.01 °C on the Celsius scale, which is approximately 32.02 °F on the Fahrenheit scale. The relationship of the Kelvin, Celsius, and Fahrenheit temperature scales is shown below.

THERMOMETER (ELECTRICAL RESISTANCE TYPE)	WATER	373.15	100	212
BOILS				
BODY TEMPERATURE		310.15	37	98.6
WATER VAPOR	WATER FREEZES	273.15	0	32
	ICE	233.15	−40	−40
ABSOLUTE ZERO	WATER	0	−273.15	−459.67
REENTRANT WELL	KELVIN	CELSIUS	FAHRENHEIT	

REFRIGERATING BATH

Temp F+40=1.8(Temp C+40)
Temp F=1.8(Temp C)+32
Temp C=(Temp F−32)/1.8
Temp K=Temp C+273.15

TRIPLE POINT CELL

The triple point cell, an evacuated glass cylinder filled with pure water, is used to define a known fixed temperature. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 0.01 °C. Thermometers to be calibrated are placed in the reentrant well.

AMPERE—A

The ampere is defined as the magnitude of the current that, when flowing through each of two long parallel wires separated by one meter in free space, results in a force between the two wires (due to their magnetic fields) of 2 x 10⁻⁷ newton for each meter of length.
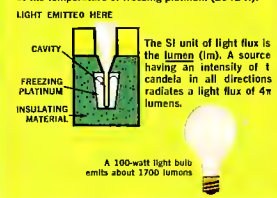
1m FORCE = 2 x 10⁻⁷N 1A
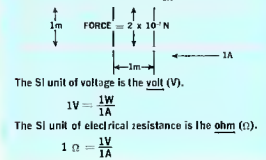
The SI unit of voltage is the volt (V).

$$1V = \frac{1W}{1A}$$

The SI unit of electrical resistance is the ohm (Ω).

$$1\Omega = \frac{1V}{1A}$$

COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents		Conversions Accurate to Parts Per Million	
1 inch	= 25 millimeters	inches x 25.4*	= millimeters
1 foot	= 0.3 meter	feet x 0.3048*	= meters
1 yard	= 0.9 meter	yards x 0.9144*	= meters
1 mile	= 1.6 kilometers	miles x 1.609 34	= kilometers
1 square inch	= 6.5 sq. centimeters	square inches x 6.4516*	= sq. centimeters
1 square foot	= 0.09 square meter	square feet x 0.092 903 0	= square meters
1 square yard	= 0.8 square meter	square yards x 0.836 127	= square meters
1 acre	= 0.4 hectare	acres x 0.404 686	= hectares
1 cubic inch	= 16 cu. centimeters	cubic inches x 16.3871	= cu. centimeters
1 cubic foot	= 0.03 cubic meter	cubic feet x 0.028 316 8	= cubic meters
1 cubic yard	= 0.8 cubic meter	cubic yards x 0.764 555	= cubic meters
1 quart (qt)	= 1 liter	quarts (qt) x 0.946 353	= liters
1 gallon	= 0.004 cubic meter	gallons x 0.003 785 41	= cubic meters
1 ounce (avdp)	= 28 grams	ounces (avdp) x 28.349 5	= grams
1 pound (avdp)	= 0.45 kilogram	pounds (avdp) x 0.453 592	= kilograms
1 horsepower	= 0.75 kilowatt	horsepower x 0.745 700	= kilowatts
1 millimeter	= 0.04 inch	millimeters x 0.039 370 1	= inches
1 meter	= 3.3 feet	meters x 3.280 84	= feet
1 meter	= 1.1 yards	meters x 1.093 61	= yards
1 kilometer	= 0.6 mile	kilometers x 0.621 371	= miles
1 sq. centimeter	= 0.16 square inch	sq. centimeters x 0.155 000	= square inches
1 square meter	= 11 square feet	square meters x 10.763 9	= square feet
1 square meter	= 1.2 square yards	square meters x 1.195 99	= square yards
1 hectare	= 2.5 acres	hectares x 2.471 05	= acres
1 cu. centimeter	= 0.06 cubic inch	cubic centimeters x 0.061 023 7	= cubic inches
1 cubic meter	= 35 cubic feet	cubic meters x 35.3147	= cubic feet
1 cubic meter	= 1.3 cubic yards	cubic meters x 1.307 95	= cubic yards
1 liter	= 1 quart (qt)	liters x 1.056 69	= quarts (qt)
1 cubic meter	= 250 gallons	cubic meters x 264.172	= gallons
1 gram	= 0.035 ounce (avdp)	grams x 0.035 274 0	= ounces (avdp)
1 kilogram	= 2.2 pounds (avdp)	kilograms x 2.204 62	= pounds (avdp)
1 kilowatt	= 1.3 horsepower	kilowatts x 1.341 02	= horsepower

† common term not used in SI   * exact

Luminous Intensity — CANDELA—cd

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a radiating cavity at the temperature of freezing platinum (2042 K).

LIGHT EMITTED HERE

CAVITY

The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4π lumens.

FREEZING PLATINUM

INSULATING MATERIAL

A 100-watt light bulb emits about 1700 lumens

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples		Prefixes	Symbols
1 000 000 000 000	= 10¹²	tera (ter'a)	T
1 000 000 000	= 10⁹	giga (ji'ga)	G
1 000 000	= 10⁶	mega (meg'a)	M *
1 000	= 10³	kilo (kil'ō)	k *
100	= 10²	hecto (hek'tō)	h
10	= 10	deka (dek'a)	da
0.1	= 10⁻¹	deci (des'ī)	d
0.01	= 10⁻²	centi (sen'tī)	c *
0.001	= 10⁻³	milli (mil'ī)	m *
0.000 001	= 10⁻⁶	micro (mī'krō)	μ *
0.000 000 001	= 10⁻⁹	nano (nan'ō)	n *
0.000 000 000 001	= 10⁻¹²	pico (pē'kō)	p
0.000 000 000 000 001	= 10⁻¹⁵	femto (fem'tō)	f
0.000 000 000 000 000 001	= 10⁻¹⁸	atto (at'tō)	a

*Most commonly used

decided on as the mass of one cubic centimeter of water at its temperature of maximum density. Since this was too small a quantity to be measured with the desired precision the determination was made on one cubic decimeter of water, but even at that the results were found to be in error by about 28 parts in a million. Thus, the meter that was established as the foundation of the system did not approximate the idealized definition on which it was based with the desired accuracy. Also the unit of mass differed from the idealized definition even as given in terms of the erroneously defined meter. So the new system was actually based on two metallic standards not differing greatly in nature from the yard of Henry II or the pound of Elizabeth I.

As a unit for fluid capacity, the founders selected the cubic decimeter and as a unit for land area they selected the are, equal to a square ten meters on the side. In this manner, while decimal relationships were preserved between the units of length, fluid capacity, and area, the relationships were not kept to the simplest possible form. Although there was some discussion at the time of decimalizing the calendar and the time of day, the system did not include any unit for time.

The British system of weights and measures, and the metric system as well, had been developed primarily for use in trade and commerce rather than for purposes of science and engineering.

Because technological achievement depends to a considerable extent upon the ability to make physical measurements, the Americans and the British proceeded to adapt their system of measurements to the requirements of the new technology of the 19th century, despite the fact that the newly developed metric system seemed to have certain points of superiority. Both the United States and Great

Britain soon had vast investments in a highly industrialized society based on their own system.
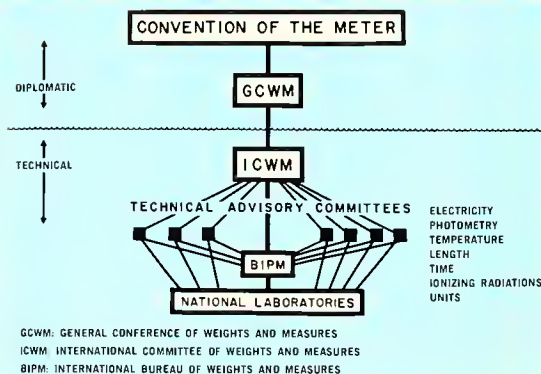
The new metric system found much favor with scientists of the 19th century, partly because it was intended to be an international system of measurement, partly because the units of measurement were theoretically supposed to be independently reproducible, and partly because of the simplicity of its decimal nature. These scientists proceeded to derive new units for the various physical quantities with which they had to deal, basing the new units on elementary laws of physics and relating them to the units of mass and length of the metric system. The system found increasing acceptance in various European countries which had been plagued by a plethora of unrelated units for different quantities.

Because of increasing technological development there was a need for international standardization and improvements in the accuracy of standards for units of length and mass. This led to an international meeting in France in 1872, attended by 26 countries including the United States. The meeting resulted in an international treaty, the Metric Convention, which was signed by 17 countries, including the United States in 1875. This treaty set up well defined metric standards for length and mass, and established the International Bureau

of Weights and Measures. Also established was the General Conference of Weights and Measures, which would meet every six years to consider any needed improvements in the standards and to serve as the authority governing the International Bureau. An International Committee of Weights and Measures was also set up to implement the recommendations of the General Conference and to direct the activities of the International Bureau; this Committee meets every two years.

Since its inception nearly 175 years ago, the number of countries using the metric system has been growing rapidly. The original metric system of course had imperfections; and it has since undergone many revisions, the more recent ones being accomplished through the General Conference of Weights and Measures. An extensive revision and simplification in 1960 by the then 40 members of the General Conference resulted in a modernized metric system—the International System of Units—which is described in detail in the accompanying chart.

NOTE: For further information see the references listed on the chart. In addition, a more complete treatment of the English and metric systems of measurement will soon be available.

CONVENTION OF THE METER

DIPLOMATIC

GCWM

TECHNICAL

ICWM

TECHNICAL ADVISORY COMMITTEES

ELECTRICITY
PHOTOMETRY
TEMPERATURE
LENGTH
TIME
IONIZING RADIATIONS
UNITS

BIPM

NATIONAL LABORATORIES

GCWM: GENERAL CONFERENCE OF WEIGHTS AND MEASURES
ICWM: INTERNATIONAL COMMITTEE OF WEIGHTS AND MEASURES
BIPM: INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES

INTERNATIONAL COORDINATION OF MEASUREMENT STANDARDS